Development of a real time tool for predicting the effects of solar wind disturbances on the ionosphere

Geomagnetic Indices Forecasting
and
Ionospheric Nowcasting Tools
GIFINT

GIFINT project

Participating Institutes

Istituto di Fisica dello Spazio Interplanetario *(IFSI), C.N.R., Roma, Italy*
Istituto Nazionale di Geofisica e Vulcanologia *(INGV), Roma, Italy*
Università de l'Aquila, l'Aquila, Italy
Rutherford Appleton Laboratory*, Didcot, U.K.*
Athens National Observatory, Athens, Greece

Users

- ***TELEDIFE*** *is a advanced technology unit of the italian Ministry of Defense, made up of sub-units from the italian Army, Air Force and Navy.*
- ***Dipartimento della Protezione Civile*** *della Presidenza del Consiglio (i.e. The italian civil protection authority, which deals with natural disasters, risks etc.)*

User needs

Forecasting and nowcasting of the ionospheric conditions in Italy and southern Europe for HF radio propagation.

Tools proposed to meet user needs

- *Geomagnetic indices forecasting* — WP100
- *Nowcasting of ionospheric radio propagation properties* — WP200
- *Post Event analysis* — WP300

Financial scheme

	Staff costs	Young graduates	Hardware	Services	Missions	Total
Consortium contribution	317		3	5	37	362
Requested ESA funding		81		5	14	100
Total	317	81	3	10	51	458

Green cells highlight ESA funding

Manpower (months)

	Staff	Young graduates	Total
WP100	8.5	33.0	41.5
WP200	7.0	11.0	18.0
WP300	9.0	11.0	20.0
Total	24.5	55.0	79.5

Green cells highlight ESA funding

Milestones

Milestone	Description	Date
ESA KO	Pilot Project Start of Activities – GIFINT starts the URD	01/01/03
GIFINT KO	Internal Kick Off meeting	03-04/02/03
M1	Release of URD for WP100 and WP200	30/04/03
M2	Mid term review of WP100 and WP200 development	31/08/03
M3	Release URD for WP300 and of first version of WP100 and WP200 outputs	20/12 /03
M4	GIFINT workshop - Release of first version of WP300 output and 2nd version of WP100 and WP200 outputs	01/ 09/04
EOC	Release of all final documents and End of Contract	31/12/04

Green cells highlight invoicing dates

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WP300 – Post event analysis activities

Personnel

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ESA Space Weather Pilot Project Workshop
Estec 16-18 December 2002

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WP100 - Tool for forecasting geomagnetic indices

Personnel

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WP100 - Tool for forecasting geomagnetic indices

Rationale

Solar wind disturbances influence the magnetosphere and ionosphere and affect communications between ground and space and from ground to ground.

This is of interest to all entities involved in communications.

We propose to develop a real time tool for predicting the effect of solar wind disturbances on the magnetosphere-ionosphere system making use of measurements taken in the solar wind at L1 typically 45 min in advance.

The input parameters to such a model will be plasma and magnetic field data measured by the ACE L1 monitor. The outputs will be the AE, AL and AU and Dst indices.

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WP100 - Tool for forecasting geomagnetic indices

Solar Wind influences the magnetosphere-ionosphere system

- Solar-cycle, annual, solar rotation variations
- Geomagnetic storms
- Geomagnetic substorms

During storms and substorms ionospheric conditions change.

Therefore, forecasting storms and substorms indirectly also forecasts disturbances in the ionosphere.

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The ANN approach

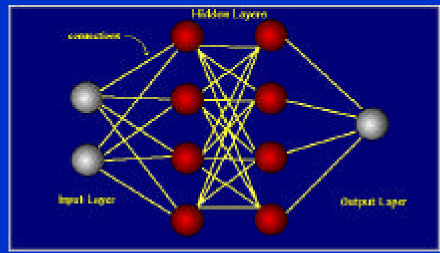
The Earth's magnetosphere is inherently in an out-of-equilibrium configuration maintained by external forcing by the Solar Wind.

Energy storage, transport and releases in the magnetospheree-ionosphere system occurs through non-linear dynamics.

The modelling of such a complex and non-linear dynamics requires the use of new approaches, not based on linear prediction filters. This is the case of "Artificial Neural Networks" (ANN), i.e. a system capable to capture the hidden parallel interactions of an input-output system and to forecast the response of such a system on the basis of the input only.

WP100 - Tool for forecasting geomagnetic indices

The ANN approach



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The ANN approach

We intend to use ANN to forecast some features of the solar driven, coupled magnetosphere-ionosphere system.

For that purpose, it is necessary to identify the output and the input

As for the outputs, a number of indices are used to estimate and monitor the geomagnetic activity and the dynamical state of the magnetosphere.

As for the inputs we intend to use plasma and magnetic field data from the ACE L1 monitor.

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The ANN approach – The outputs

The auroral electrojet indices (AU, AL, AE=AU-AL, AO=(AL+AU)/2), derived from high latitude fluctuations of the magnetic field horizontal component at Earth's surface, give a measure of the strength of the auroral electrojets, and respond primarly to the substorm phenomena.

The Dst index gives an estimate of the magnetic field perturbation due to the ring current enhancements and, therefore, well describes the intensity and duration of geomagnetic storms.

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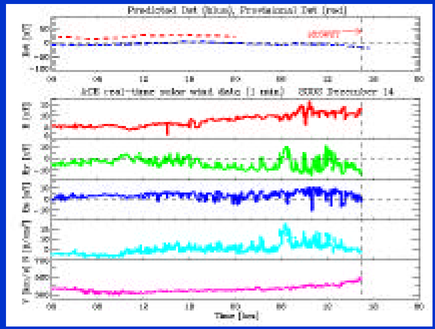
Example of ANN Dst prediction from the DMI web site



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The time lag between L1 and the Earth

Usually, the delay between the time of measurement at L1 and the arrival at the Earth orbit is calculated as DT = L/V_{SW}

However, a number of papers over many years has shown that the actual delay can differ considerably from that value. The last such paper, to my knowledge, is:

Variable time delays in the propagation of the interplanetary magnetic field,
D. R. Weimer et al. JGR, vol. 107, No. A8, 10.1029/2001JA009102, 2002

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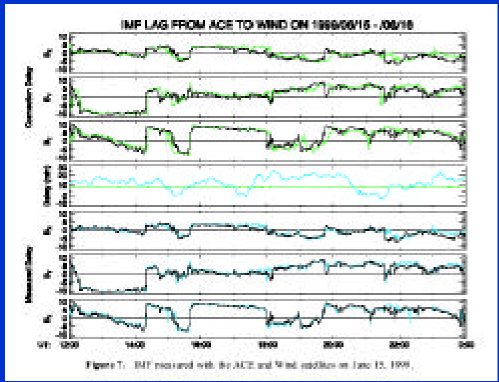

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Example of evolution of normal to SW structures

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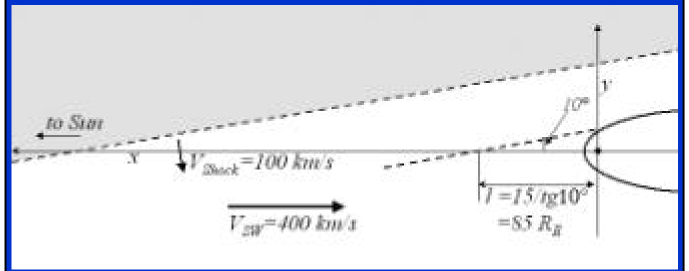
Effect of the orientation of Solar Wind structures on L1 delays



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The time lag between L1 and the Earth Conclusions from Weimer et al.

- *Our findings strengthen confidence in our ability to predict geospace environments based on upstream measurements. There remains however a serious problem, in that there is an uncertainty in the timing of events...*
- *Obviously, the multiple satellite described in this paper cannot now be used for making predictions, as there is only one satellite transmitting solar wind data in real time.*
- *It would be ideal if the phase front orientation could be determined using real-time data from a single spacecraft in an L1 orbit, or even closer to the Sun. As mentioned above, we have made some progress along these lines with the minimum variance technique, to be the subject of a separate paper.*
- *The ideal solution would be to place three monitors at L1, spaced 120 RE apart in their halo orbit so that tilts in the phase fronts can be determined.*

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WP100 - Tool for forecasting geomagnetic indices

Technical Description of the work

- *Set up a service displaying different forecasts of Dst and AE based on different algorythms documented in the literature.*
- *Check the performance of the various algorythms (also though PEA – WP 300)*
- *Investigate the possibility to include as an input parameter:*
  - *the normal to Solar Wind structures as measured at L1.*

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WP100 - Tool for forecasting geomagnetic indices

Data availability

- *AE and Dst are easily accessible and agreement can be easily reached for using them for the described purpose*
- *ACE will certainly operate until October 2003 and there is no doubt the mission will be further extended for two more years or until a new L1 monitor is operational.*

WP200 - Tool for nowcasting ionospheric radio propagation conditions

Rationale

The space weather effects on radio wave communications, navigation and surveillance systems are largely determined by ionospheric electron density and total electron content structure and its dynamics.

We describe a system for real-time monitoring the state of the ionosphere over Europe based on TEC measurements.

Such a system is relevant for:
- *the identified users*
- *various other users (e.g. EGNOS & GALILEO)*

Similar systems already exist in the US and Australia.

WP200 - Tool for nowcasting ionospheric radio propagation conditions

Personnel

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WP200 - Tool for nowcasting ionospheric radio propagation conditions

Technical Description of the work

Develop a software tool for the real-time mapping of the ionosphere over Europe

Certify its performance during geomagnetically quiet and disturbed time period

Ensure its reliability

WP200 - Tool for nowcasting ionospheric radio propagation conditions

Description of the proposed tool

Definition of SIRM (Simplified Ionospheric Regional Model)

SIRM is based on 12 couples of Fourier coefficients An and Yn linearly dependent on solar activity and on geographic latitude:

$An = (a^1_n \ddot{o} + a^2_n)R12 + a^3_n \ddot{o} + a^4_n$

$Yn = (b^1_n \ddot{o} + b^2_n)R12 + b^3_n \ddot{o} + b^4_n$

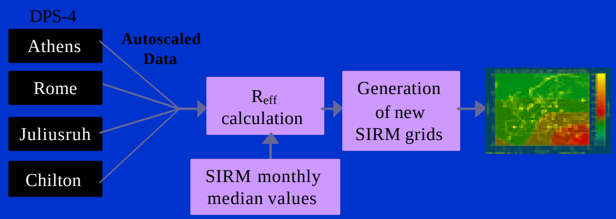
a^j_n and b^j_n are calculated using a linear regression analysis versus the latitude.

We propose a <u>real-time updating</u> method of SIRM with <u>autoscaled ionospheric parameters</u> observed by four European DPS ionosondes in order to have a <u>realistic mapping of the ionosphere over Europe in real-time</u>, especially during storm periods.

WP200 - Tool for nowcasting ionospheric radio propagation conditions

Description of the proposed tool - 2

Real time values of foF2 at one location can be determined from the SIRM model by using an effective sunspot number, R_{eff}, instead of the R12 index.



WP200 - Tool for nowcasting ionospheric radio propagation conditions

Description of the proposed tool - 3

The effective sunspot number, R_{eff}, is determined by minimising the following mean square error:

$$\Delta = \frac{1}{n}\sum_{i=1}^{n}\left(foF2_{obsi} - foF2_{cali}\right)^2 .$$

where n is the number of stations,
$foF2_{obsi}$ is the observed foF2 at station i
$foF2_{cali}$ is the calculated foF2 at station i
$foF2_{cali}$ is calculated for different sunspot numbers to determine the minimum mean square error and thus R_{eff}.

Reference stations	Geographic Latitude	Geographic Longitude
Athens	38.1	23.9
Rome	41.8	12.5
Chilton	51.6	358.7
Juliusruh	54.6	13.4

WP200 - Tool for nowcasting ionospheric radio propagation conditions

Description of the proposed tool - 4

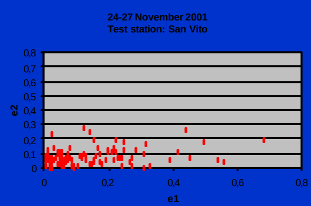
Relative errors.

$$e1 = \frac{\left|foF2_{obs} - foF2_{SIRM}\right|}{foF2_{obs}}$$

SIRM error

$$e2 = \frac{\left|foF2_{obs} - foF2_{SIRM\,Reff}\right|}{foF2_{obs}}$$

R_{eff} based SIRM error



WP200 - Tool for nowcasting ionospheric radio propagation conditions

Conclusions

The proposed tool has already been preliminary tested.

- *Real-time predictions of foF2 at middle latitudes in Europe can be improved by using real-time observations at a grid of 4 reference stations spread over Europe.*
- *For storm periods real-time predictions are much improved comparing to SIRM.*
- *Real-time predictions are more successful at the centre of the mapping area.*

The tool has to be made available on a routine basis through a suitable hardware and software system: ***this is the goal of the present proposal.***

The data for this tool are available and will be so in the future.

Thank you